SURVIVAL AND TRANSPORT OF ENTERIC BACTERIA AND VIRUSES IN THE NEARSHORE MARINE ENVIRONMENT - AN ANNOTATED BIBLIOGRAPHY

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INTRODUCTION

This bibliography was prepared as part of the U.S. EPA Buzzards Bay Project by staff members of the Barnstable County Health and Environmental Department. Although the original intent in compiling this literature was for use in preparing a report on the investigation of coliform sources in Buttermilk Bay, it was realized that annotations of the literature used therein could serve as summary of the state of knowledge relative to enteric bacteria and virus survival in the marine environment. In addition to literature relative to this specific subject, research on the survival and entrainment of biological components of sanitary wastes in groundwater is included so that the implications of on-site subsurface sewage disposal systems near surface waters could be appraised.

In considering environmental studies involving bacteriological monitoring, there are at least two basic concepts which should be understood by the reviewer. Most importantly, the concept of an indicator organism should be clearly understood. Regarding water quality in shellfish harvesting areas, the density of a biological indicator organisms has historically been the basis for many of our conclusions regarding water quality. An indicator organism is a biological component (virus or bacteria) which has been shown, in its occurrence, to exhibit a correlation with the occurrence of another organism or set of organisms. In shellfish harvesting areas, this correlation is with the enteric pathogens. Indicator organisms are necessary due to the fact that direct measurement of the many pathogens is precluded by the lack of cost-effective reliable methods for enumeration. In addition to the availability of enumeration techniques, the existence of a large number (over 100 enteric pathogenic viruses alone) of agents renders their direct measurement impractical.

There is no doubt that the current indicator system used in Massachusetts and many states (fecal coliform) has been the subject of much controversy. The issue can generally be dissected into questions. Initially, the question of fecal specificity arises. The fecal coliform group contains some organisms (notably thermotolerant Klebsiella sp.) which have been shown in papers reviewed herein to be non-fecal specific. The second, and more complex issue, is the use of the indicator applied in situations where non-point source pollution has been shown to be the primary cause. The lack of epidemiological studies linking the occurrence of enteric diseases with impact by non-point sources is notably lacking. Despite these shortcomings, it is evident that the present indicator, fecal coliform, will continue to be used until such time as the body of scientific investigation presents an adequate alternative.
An additional aspect of reviewing the studies herein could best be expressed by these authors as a cautionary note. It is important to understand that there are many variables affecting the survival of enteric pathogens and indicator organisms in groundwater and the marine environment. This fact, and the fact that enumeration techniques for many enteric pathogens have undergone significant improvements in recent years should compel the reviewer to consider the date of the study reviewed and site-specific variables which may make direct transference of conclusions to another study area inappropriate. This can clearly be seen when reviewing information on viruses. The field of environmental virology is still in its embryonic state, and enumeration/culture techniques of recent years have far surpassed those of prior years rendering some comparisons inappropriate based simply on the date of the study.

For ease of reference, the bibliography is broken into several sections: bacterial and viral survival and transport in marine waters; bacteria and virus survival and transport in groundwater; effect of stormwater on bacteriological quality of coastal water; effect of waterfowl bacteriological quality of coastal water; and effect of marine craft usages on bacteriological quality of coastal water. Each section includes both historical work and current research on parameters affecting water quality. The brief annotations are intended to summarize the results of each study and allow readers to identify those papers they wish to read in greater depth.

We express our gratitude to members of a number of state and federal agencies, who through the process of report review and interest have forwarded to us some of the articles presented herein. Dr. James Vaughn of the Brookhaven National Laboratory, whose work is reviewed herein, provided for an important initial insight into the issue of entrainment of enteric organisms in groundwater both through correspondence and supplying us with copies of relevant work in the area. Ira Somerset of the United States Food and Drug Administration following review of our initial reports in Buttermilk Bay pointed us toward some of the "gray" literature on marine craft usage and also fecal indicator survival in the marine environment literature. We also thank the numerous shellfish wardens, biologists, members of the Shellfish Sanitation Program of the southeastern region of D.E.Q.E. and interested individuals who periodically dug through their files for literature supporting this project.

We hope this list will serve as a good introduction to the existing scientific literature and will assist the reader in identifying sources of information which can be applied to maintain and improve our coastal water quality.
BACTERIA AND VIRUS SURVIVAL AND TRANSPORT IN MARINE WATERS


Poliovirus 1 showed a typical loss of 3 logs of infectivity in 3-5 days at 24 C in marine water from Gulf of Mexico. Viral infectivity loss occurred in raw, filter-sterilized and autoclaved marine water and artificial seawater 1,10,20 g/kg salinity. 6 Figs. 14 Refs.


Light is reported to be an important factor in reducing fecal coliform. Time required for fecal coliform density to decrease by 90% (T-90) varied from a max of 40 hrs during the night to 1.9 hours just before noon. Equation for T-90 and light intensity given: T-90 = 3.4 x I^-0.42 where I=hourly solar radiation in MJ/m^2 10 Figs. 10 Refs.


Solar radiation was found to have some inactivating effect on poliovirus type 1 in the absence of any natural or synthetic photosensitizing agent. Photoinactivation of poliovirus in lake water was retarded by the presence of blue-green algae. Light inactivation was less important at a depth of 6 inches. Clay displayed a protective effect against light and thermal deactivation. 5 figs., 15 refs.


Maximum coliphage inactivation was observed in both untreated natural and heavily polluted marine waters; coliphages showed maximum resistance to inactivation in filtered and autoclaved clean and polluted seawater. In vitro study. 6 figs., 35 refs.

Coliphages showed greater resistance to marine environment than their bacterial host, E. coli. Rate of bacterial inactivation in descending order was: total coliforms (inactivated soonest) fecal coliform, Salmonella-Shigella, coliphages and fecal streptococci. 6 Figs. 19 Refs.


Literature review; 58 references for work prior to 1959. Reviewed effects of 1) adsorption/sedimentation; 2) sunlight--bacteria died rapidly in shallow layers of seawater exposed to midsummer sunlight; the lethal effect did not extend > 20 cm.; 3) lack of nutrients--organic nutrient addition decreased death rate of E. coli; 4) toxic substances; 5) bacteriophages and predators; 6) sterilization


Literature review of the factors affecting coliform die-off rates. Light intensity is single most important factor in bacterial die-off. 61 refs.


The major effect of small unsewered towns along the river is to supply nutrients which support growth of indigenous river flora. The effect of large urban centers, which release primary and secondary sewage, is to provide nutrients and an inoculum of E. coli. 14 figs., 13 refs.


After 7.1 days at 0 C under ice cover, the relative survival rate was total coliform < fecal coliform < fecal strep with 8.4%, 15.7% and 32.8%, respectively, of the initial populations remaining viable. These rates are higher than previously reported and
suggest that survival rate is best at 0 C under ice cover. MPN and MF did not provide comparable results near the pollution source. 11 figs., 44 refs.

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Human enteric viruses are present in significant numbers around non-treated sewage outfalls as well as in secondarily treated, chlorinated sewage outfalls. Average viral concentration was only 1-2 log$_{10}$ less at outfalls discharging chlorinated effluent than at outfalls discharging untreated effluent. 3 figs., 19 refs.

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A rural watershed area of 849 ha, with an animal population of 0.6 animal/ha, discharged between 7.5 x 10$^6$ and 669 x 10$^6$ fecal coliform/ha/day to the estuary; rate was seasonal and depended on water flow. Persistence of bacteria in the estuary may increase the pollution level contributed by the watershed, especially at low temperatures. Estimates worked out for dilution volume per hectare of farmland necessary to meet shellfish standard of 14 FC per 100 ml. 7 figs., 35 refs.

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Survival of E. coli as affected by time, water temperature, dissolved oxygen, salinity, and montmorillonite. Relationship between pairs of variables was studied. Bacterial survival varied seasonally; water temperature was most important factor in predicting survival. 6 figs., 25 refs.

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Evidence indicates that a virus-inactivating agent(s) of a microbiological nature was present in both clean and sewage-polluted seawaters, but not present in fresh mountain stream waters. Antiviral activity lost when samples were subject to boiling, autoclaving or filtration through .22 or .45 but not 1.0 micron.
filter. Data suggest that antiviral activity of seawater was is related to growth activities of microorganisms. 8 figs., 10 refs.


In the absence of sunlight, fecal coliform and fecal strep survived for days, whereas in the presence of sunlight 90% of FC and FS were inactivated within 30-90 min and 60-180 min., respectively. Bactericidal action of sunlight penetrated 3.3 m of clear seawater suggesting visible rather than UV light was responsible. FS were more stable than FC; T90 with no light was 21-48 h for FC and 36-84 h for FS. 6 figs., 15 refs.


The logarithm of the coliform count was found to decrease fairly regularly with increase in the cumulative radiation. Surface radiation required to produce 90% mortality increased with advancing season, from April to September. 12 figs., 7 refs.


Data demonstrates a loss of viral titer when seawater is filtered or centrifuged, or when fine clays and sediments are added to seawater. Presence of organic matter was shown to cause viral de-adsorption from clay particles. Data suggests that viral survival is enhanced by viral adsorption to suspended particulates in water. 13 figs., 18 refs.


Sediment prolongs the survival time of coliforms in marine waters, and at times can support coliform growth. Longer survival in sediment attributed to higher organic content of sediment than seawater. There were sufficient nutrients in the sediments in areas of sewage effluent discharge, as well as areas free from this type of pollution, to support bacterial growth. 6 figs., 20 refs.

In waters receiving secondarily treated sewage effluent, generally 100-1000 times more coliform and 10-100 times more fecal coliform were detected in the sediment than in the water column. Enteroviruses also in greater concentration in sediments. 4 figs., 17 refs.


Literature review of epidemiological work on these two diseases, including information on viral survival in the environment. 5 figs., 167 refs.


E. coli survived and grew in diffusion chambers in both aerobic and anaerobic portions of the water column in a reservoir receiving thermal effluent. E. coli survived and grew for 2-3 weeks in both ambient and thermally altered water at each depth tested. Results suggest that presence of E. coli is not an indicator of recent fecal contamination. 9 figs., 29 refs.


Extensive literature review of viruses in marine environment, including information on waterborne disease outbreaks, fate and transport of viruses in the environment, and methods for viral detection. Discusses need to reevaluate coliform index in view of recent information on waterborne viral illness. 20 figs., 148 refs.


Strong positive correlation found between virus concentration in water and MPN of presumptive total coliforms in sediment. Indicator bacteria and Salmonella were more abundant in sediments than overlying waters. No correlation between virus numbers in
overlying waters with coliform bacteria indicators. Sediments may act as reservoirs for coliforms and viruses. 7 figs., 46 refs.


No significant relationship was demonstrated between virus concentration in oysters and the bacteriological and physiochemical quality of water and shellfish. Greater numbers of bacteria were isolated after rainfall; turbidity was related statistically to organic content and fecal coliform number in water. Authors postulate this may be due to the release of sediment bound bacteria into the water column after rainfall. Current bacteriological standards for shellfish waters do not accurately reflect occurrence of enteroviruses. 6 figs., 44 refs.


Human enteric viruses associated with sewage sludge disposal were isolated from sediments up to 17 months after sludge dumping ceased. A protective sludge-sediment matrix and generally low (ca. 7C) temp may have contributed to the prolonged survival. No correlation seen between indicator bacteria and viruses. 7 figs., 31 refs.


Fecal coliform concentrations increased significantly in vicinity of dredging in Mississippi River; disturbance of sediments by dredging results in release of sediment bound coliforms. 3 figs., 5 refs.


Survival of A. hydrophila was increased in pulp mill effluent and decreased in nitrogen fertilizer factory effluent. A. hydrophila numbers were positively correlated with phytoplankton density and thus indirectly by concentrations of nitrate, phosphate and organic carbon. Fecal coliform densities were significantly higher at outfall and downstream from both effluents, and
frequently exceeded recreational water standards. 13 figs., 35 refs.


River bottom sediments were eluted with phosphate buffer and found to contain hexose, protein and ammonia-nitrogen 4-6 times that of overlying water. Selected strains of enterobacteriaceae (including \textit{E. coli}) were able to utilize these nutrients. 7 figs., 21 refs.


Demonstrated the growth of selected enteric bacteria in stream water below a sewage outfall. Maximum growth occurred at 30°C, while some growth occurred at 20 and 5°C. Generation times are given for individual bacteria. 7 figs., 25 refs.


Growth of enteric bacteria, including \textit{E. coli}, most pronounced at 16°C. River bottom sediment extract contained enough nutrients to support growth. 9 figs., 11 refs.


Two enteroviruses were inactivated more rapidly in lake than in sterile lake water. Virus coat proteins were degraded and perhaps used by microorganisms. 2 figs., 6 refs.

UV light at 253.7 nm. effective in deactivating common enteric viruses. 7 figs., 34 refs.

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Sediment chambers used. For V. cholerae, growth and extended periods of survival occurred in sterile sediments, sterile waters and non-sterile waters, but not in non sterile sediments. In contrast, E. coli decreased rapidly in both sterile and non-sterile marine waters. Suggest that V. cholerae survives better in estuarine waters than E. coli. 9 figs., 20 refs.

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High concentrations of total and fecal coliform were found in estuarine waters which had large areas of adjacent tidal wetlands. Organic nitrogen exhibited high positive correlation with bacterial numbers. Tidal wetlands export large amounts of organic nitrogen; authors hypothesize that tidal wetlands create an environment suitable for survival or growth of coliforms. 6 figs., 29 refs.

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Evidence was found for the toxicity of heavy metals toward E. coli in natural seawater. Heavy metals appear to inhibit growth but not respiration. 13 figs., 59 refs.

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Extensive review article of research on use of freshwater wetlands for sewage treatment. Includes information on removal of nutrients, bacteria and viruses. 71 refs.

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V. parahaemolyticus was found to adsorb onto chitin. E. coli and Pseudomonas fluorescens did not. Adsorption efficiency greater in lower salinity water. Adsorption is one of major factors in determining distribution of V. parahaemolyticus in estuary. 6 figs, 13 refs.


Solar radiation can be an important agent controlling the distribution and abundance of E. coli and viruses in seawater. Waves greater than 370 nm can cause mortality. The depth for a 10-fold reduction exceeds 5m even in productive water. 6 figs., 48 refs.


Dilution, predation and the bactericidal action of seawater account for more than 99% of the decrease in coliform bacteria numbers; of these, bactericidal action is most important. 9 figs., 17 refs.


Greater than 99% of enteric viruses added to estuarine sediment became adsorbed to sediment; this association may play a major role in viral hydrotransportation and survival. The presence of soluble organic matter in the form of secondary sewage effluent or humic acid did not effect the pattern of adsorption. 14 figs., 29 refs.


Virus adsorption to sediment greatly increased survival time. The time required to inactivate 99% (T-99) of poliovirus increased from 1.4 days in seawater alone to 6 days for virus adsorbed to sediment at an unpolluted site; at a polluted site T-99 increased from 1 h to 4.25 days by virus adsorption to sediment. 3 figs., 25 refs.

Statistical analysis of the relationship between viruses in seawater or in sediment and other variables measured yielded only one significant association: the number of viruses in sediment was found to be positively correlated with the number of fecal coliforms in the sediment. Viral numbers in sediment were not correlated with total coliform or Clostridium in sediment or water; or with fecal coliform in water; or with pH, turbidity, rainfall, or salinity. 5 figs., 41 Refs.


Study using Polivirus 1 (LSc strain). Sediment was capable of protecting virus from inactivating effects of microorganisms, heat and salt. Anaerobic environment did not influence virus survival. Addition of bacterial nutrients enhanced virus survival, possibly by virus adsorption to resulting bacterial populations; however organic material naturally present in sediment did not enhance virus survival in seawater. Virus adsorption to sediment appears to be the most important interaction that retards virus inactivation. 10 figs., 38 Refs.


The study demonstrated the extended survival of sediment-bound E. coli, in both sand and silty-clay sediments. 3 figs., 39 refs.


Shellfish accumulation of sediment-bound viruses was minimal when sediments remained undisturbed. Incidence of viral uptake by shellfish was higher when sediments were intentionally resuspended. Study suggests that virus sampling be conducted near the sediment-water interface rather than mid-depth or at the surface. 6 figs., 20 refs.

Survival of E. coli and enterococci were correlated with temperature. In relatively low-nutrient estuarine waters, temperature may exert major control on coliform populations. Enterococci survived longer than E. coli in the estuary, but less well in the more eutrophic salt marsh. 7 figs., 44 refs.


Polio 1 and Echo 1 viruses evaluated. Poliovirus survival was prolonged at 24 and 37 C but not at 4 C in the presence of sediment. Prolonged survival was likely due to adsorption. Poliovirus detected on day 33 at 24 C with sediment but not at day 18 without. Adsorption of enteroviruses to estuarine sediment protects against thermal deactivation. 5 figs., 17 refs.


Early paper indicating that seawater showed definite virucidal property hypothesized to be due to the combined effect of its chemical composition and an unknown inhibitory substance. 6 figs., 15 refs.


Higher numbers of microorganisms found in sediments than overlying waters; populations found were sufficient to be
considered a health hazard under existing standard indicator densities. Discusses role of resuspension of sediments. 10 figs., 21 refs.

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E. coli cells inoculated into natural estuarine water were reduced from 10^6 bacteria per ml to less than 10 after 10 days when protozoa were present, and to 10^4 bacteria per ml when no protozoa were present. 4 figs., 16 refs.

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Decline in E. coli numbers in estuarine waters was significantly greater in presence of both naturally occurring microbial predators and solar radiation than when either factor acted independently. Susceptibility of bacteria to light induced decay varied as follows: Klebsiella pneumoniae, E. coli, Salmonella typhi-murium, Streptococcus faecium. 4 figs., 14 refs.

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Virus remained relatively stable within oyster tissues stored at 5 C for at least 28 days. Of all tissues examined, the digestive gland showed the greatest retention of virus. There was no multiplication of the virus, but simply retention. 8 figs., 9 refs.

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Virus-carrying oysters immersed in estuary waters with temperatures less than 7 C retained fully infectious enteroviruses for at least 4 months during the winter season. 8 figs., 19 refs.

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Metcalf, T. G., C. Wallis and J. L. Melnick. 1974. Virus enumeration and public health assessments in polluted surface water contributing to transmission of virus in nature. In:


Literature review on the subject, notably downplaying the role of light-induced mortality. 48 refs.


Supports a hypothesis that indigenous microflora play a major role in the elimination of E. coli from the environment. Decrease in the number of E. coli was strongly affected by the size of the microbial population; almost no decrease was detected in autoclaved water. 3 figs., 7 refs.


Viral inactivation rates were primarily affected by water temperature. There was differential stability among the viruses. Lower temperatures stabilized the virus but the mechanism is not known. 8 figs., 18 refs.


In seawater, mortality rate of coliforms was approximately doubled by a 10°C rise in temperature. The resistance of coliform to die-off in seawater may vary with the source of the sewage. 1 fig., 8 refs.


The distribution of enteroviruses among water, suspended solids and compact sediments in a polluted estuary was examined. Viruses were found adsorbed to: 72% of the suspended solids tested, 47% of the fluffy sediments (uppermost layer of bottom sediments), and only 5% of the compact bottom sediments. Virus was found in only 14% of the water samples tested. Viruses remained infectious for 9 days when suspended in water but for 19 days when adsorbed to solids. 7 figs., 34 refs.


In areas of sewage outfalls, coliforms were found in sediments in areas beneath the path of movement of the effluent in the overlying water. Survival time in sediment not quantified. 5 figs., 17 refs.


In marine sediments, E. coli appeared to be protected from phage attack by presence of sediment and other sorbed colloidal materials. The protection of E. coli and possibly other fecal bacteria may result in their accumulation in marine sediments, producing a possible health hazard in estuaries and lagoons if the bacteria are desorbed following dilution as a result of heavy rainfall. 8 figs., 27 refs.


Clay can inhibit the normal predation of E. coli by predators.


Significant portions (>80 %) of the fecal indicator organisms were directly associated with suspended sediment. Counts however were not found to be correlated with suspended
Enteroviruses are more resistant to inactivation processes in the marine environment than coliform organisms. The time at which the rapid inactivation phase of viruses starts appears to be closely associated with the period of logarithmic growth and maximum bacterial concentration in the seawater.


The results show that Streptococcus faecalis, S. aureus and Streptococcus sp. readily lost viability in the absence of organic nutrients. Bacterial populations dropped 2-4 orders of magnitude in 1 to 4 days. Bacterial populations did not drop when added to samples of sterile sewage, probably due to availability of nutrients and removal of competitors. 5 figs., 17 refs.


Suggests that lowering pH can prolong survival of E. coli in a dilute environment. 6 figs., 30 refs.


Echovirus 1, coxsackie viruses B3 and A9 and poliovirus 1 survived longer when associated with sediments than when suspended in estuarine water. When the estuarine water was polluted with secondarily treated sewage effluent, virus survived for prolonged periods in sediments, but not in the overlying water. 5 figs., 24 refs.

Variations in the ability to elute viruses off sediments were due to differences in pH, virus types and composition of sediments.

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Bactericidal properties of raw, fresh seawater exhibited seasonal variation; the time required for the disappearance of 90% of introduced E. coli was 6.0 days in early November and 0.6 days in July. When the organic content of raw water was raised approx. tenfold by enrichment with peptone, the average time for the mortality of 90% of the coliform population was about 3 times that of raw water. 7 figs., 13 refs.

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In near-shore coastal waters, survival of E. coli was enhanced by effluent from a rum distillery. Authors conclude that E. coli is not a good indicator of recent fecal contamination in tropical waters. 7 figs., 32 refs.

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Fecal coliform concentrations showed a 100 to 1000 fold increase in mud compared with overlying water. Survival of Salmonellae in mud closely parallels that of fecal coliform. 5 figs., 21 refs.

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Using natural seawater, bacterial mortality was shown to be inversely related to water temperature. Nutrients were not controlled. For E. coli, the highest fatalities were found to occur among cells exposed to 14.5 C as opposed to 8.9 C. 9 figs., 25 refs.

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5 year study of microbiological water quality indicators including total coliform, fecal coliform, E. coli, fecal streptococci, enterococci, enteroviruses, and physiochemical parameters including pH, temperature, turbidity, and nutrient levels. 7 figs., 34 refs.


Sediments show 100-1000 times the number of indicator organisms as overlying waters. 9 figs., 9 refs.


Numbers of V. parahaemolyticus were positively correlated with fecal pollution, including levels of E. coli, Clostridium perfringens, and enterococci. This is probably due to biostimulation of food chain by addition of wastewater effluents. 10 figs., 28 refs.


The addition of low concentrations of organic substances, including feces, to seawater enhanced survival of E. coli at 3-5 C. At 22 C, organic substances promoted growth of E. coli, allowing a 40 fold increase and enabling persistence up to 18 weeks. Apparently at this temperature the organic material overwhelmed bactericidal qualities of the seawater permitting growth. Addition of organics did not enhance virus survival. 7 figs., 9 refs.
BACTERIA AND VIRUS SURVIVAL AND TRANSPORT IN SOIL AND GROUNDWATER


Literature summary on the entrainment of pathogens and indicator organisms in groundwater. 23 refs.


Literature review. Viruses act as electrically charged colloidal particles which may adsorb to surfaces outside the host cells. The sorptive interactions between viruses and surfaces influence the behavior of viruses in soil and other environments. 8 figs.


Most fecal coliform were removed in the first 2 ft (60 cm) of soil. Infiltration of fecal coliforms was slightly higher when initial flooding followed a dry period.


Septic effluent was applied to subsurface to three soil types of 80, 41 and 7.6 % sand content. Applied effluent averaged $1.108 \times 10^6$ plus or minus $1 \times 10^4$ FC/100 ml. Fecal coliform were present in leachate collected 120 cm below septic lines only on a few occasions. Coliphages also showed limited mobility. 7 figs., 13 refs.


Adsorption rate of virus to soil was correlated with cation...
exchange capacity, specific surface areas, organic content and pH of soil. Soil which did not adsorb virus had coarsest texture and highest pH. High negative correlation with pH is due to the amphoteric nature of virus coats; lowering soil pH increases the positive charge on the virus particle making it more likely to adsorb to soil surface. 7 figs., 14 refs.


Enteroviruses and rotavirus SA11 were applied to 80 cm sand columns at a number of infiltration velocities. Tertiary treated effluent showed best adsorption; adsorption was poor for secondary effluent, probably due to increased organic content. Presence of surfactants significantly reduced adsorption. Results indicate that sand, even of low clay content, and at infiltration velocities of 0.5 to 5 m/day, is an excellent material for the elimination of viruses from contaminated waters. 7 figs., 22 refs.


Extensive literature review of behavior of viruses in soils. Summary discussion points out the need for site-specific data to predict viral behavior. 9 figs., 301 refs.


Ionic strength and pH of soil water greatly affect poliovirus adsorption to soil. Cycles of rainfall and effluent application, resulting in ionic gradients, caused viral elution off soils. Poliovirus survived in soil at 4 C to 20 C for up to 84 days. 9 figs., 21 refs.


Septic tank drainfields installed in unsuitable soils were implicated as a major source of coliform contamination of coastal waters. Higher levels of indicator bacteria were found in
catchments with greater number of septic systems, in both wet and dry conditions. Authors calculate that densities of more than 0.15 septic drainfields per acre (equals one septic drainfield per 7 acres watershed) result in bacterial levels high enough to cause shellfish closure. 8 figs., 17 refs.

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Fecal coliform applied to soil persisted for at least 204 days. In summer, aftergrowth of low numbers of fecal coliforms was noted. Die off rates were highest in winter. Both total and fecal coliforms migrated to soil beneath surface, but few moved more than 5 cm. 10 figs., 12 refs.

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Enteroviruses are efficiently retained by sludge-soil mixtures; viruses were not detected in 40-60 foot wells monitored at the site. 6 figs., 17 refs.

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Movement of poliovirus 1, reovirus 3 and bacteriophage 0X174 was studied in 8 different soils. Adsorption and entrainment were related to soil cation exchange capacity (CEC), organic content, percent clay, pH, and specific surface area. Poliovirus recovery was correlated with low CEC and high organic carbon and clay content. Recovery of 0X174 was related to low CEC and low organic carbon. Soil CEC values of 23 meq/100 g were sufficient to remove at least 99% of poliovirus within 33 cm. 6 figs., 22 refs.

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Literature summary. Soil moisture content, temperature, pH, availability of nutrients and antagonism are the principle factors influencing the survival of enteric bacteria in soils. The
amount of information on virus survival in soil is very limited, but viruses appear to survive at least as long, if not longer than enteric bacteria. 5 figs., 63 refs.


Primary and secondary sewage effluent applied to 240 cm soil column, using loamy sand. Adsorption of virus to soil, and desorption by distilled water were similar for both effluents. The greater concentration of organics in primary effluent did not appreciably affect the removal of poliovirus by the soil. 5 figs., 22 refs.


Review of recent information on variables affecting microorganism survival and movement through soil, and fate of pathogens in subsurface waters, including results of field studies. 12 figs., 99 refs.


Overview of the problems associated with groundwater microbiology. Cites studies documenting coliform travel in groundwater a distance of 900 m from site of application, and viral travel to 408 m. 21 refs.


Secondary sewage effluent was land-applied. After percolation through 9 meters of sandy loam soil no viruses or Salmonella spp. were detected in well samples, and the number of fecal coliform, fecal streptococci and total bacteria were decreased by 99.9%. 6 figs., 19 refs.

Goyal, S. M. and C. P. Gerba. 1979. Comparative adsorption of human enteroviruses, simian rotavirus, and selected bacterio-

Viral adsorption to soil shows high variability among viral types, and among different strains of the same virus. Adsorption was also influenced by soil type and soil pH; soils with pH less than 5 were generally good adsorbers. Results emphasize that no one virus or soil can be used as sole model for predicting viral adsorption. 6 figs., 30 refs.


*E. coli* and *Streptococcus faecalis* survived in groundwater to 32 days. Neither bacteria was detected in wells 30 m distance on day 32, but sufficient time may not have elapsed for travel in groundwater to this distance. Rainfall caused a peak in the bacterial numbers in wells. 5 figs., 8 refs.


Primary factors affecting virus survival in soils were temperature and viral adsorption to soil. Viral survival was also dependent on soil moisture, presence of aerobic microorganisms, soil levels of resin-extractable phosphorus, exchangeable aluminum, and soil pH. 12 figs., 18 refs.


Poliovirus type 1 and Echovirus 1. Viruses exhibited a differential downward migration; 100 times more poliovirus than echovirus migrated 5-10 cm. after 5 days. Results indicate that the rate of virus inactivation was dependent on rate of soil moisture loss; drying cycles during the land application of wastewater enhance virus inactivation in soils. Maximum survival measured was 60 cm. 9 figs., 25 refs.


Literature summary with many useful charts for entrainment of viruses in groundwater, including the effects of various
parameters on entrainment. 7 figs., 56 refs.


*Streptococcus faecalis* survived up to 12 weeks in soil under cool, moist conditions (4 and 10 °C). Freeze-thaw cycles killed the bacteria. Bacteria exhibited variation in die-off among soil types. 8 figs., 15 refs.


Poliovirus 1 in sewage effluent traveled a maximum of 160 cm through a 250 cm column packed with calcareous sand. Most viruses were adsorbed in the top 5 cm of soil. Flooding with deionized water caused desorption from the soil and increased virus movement in the soils. 99.99% or more removal of virus would be expected after passage of secondary effluent through 250 cm of calcareous sand unless heavy rains fell within 1 day of application. 9 figs.; 16 refs.


Travel of Echo 1, Echo 29, and Polio 1 viruses through 250 cm soil columns. Greater than 99.9% of viruses were removed by 160 cm. Virus movement thru loamy sand roughly parallels travel of fecal coliform. 8 figs., 15 refs.


Movement of poliovirus during unsaturated flow of sewage thru 250 cm soil columns was much less than during saturated flow. Viruses moved 160 cm under saturated flow, vs. 40 cm during unsaturated flow. 4 figs., 13 refs.


The presence of proteinaceous materials decreased the ability of silicate minerals to adsorb virus; extraneous organic material not only competed for adsorption sites but also desorbed the virus from the minerals. Organics in treated wastewater reduced the total adsorption capacity and rate of adsorption. 6 figs, 18 refs.


Poliovirus was isolated from drinking water from a well located more than 300 feet from the edge of a sewage drainfield. However, the well casing was in limestone so that percolation through soil may not have been involved. Actual source of virus in the well water was not determined. 2 figs., 4 refs.


The longevity of coliform organisms, typhoid bacilli and enterococci in soil was prolonged with an increase in the organic content of the soil. Coliforms were found to persist in soil for long periods, while enterococci died out rapidly. 5 figs., 13 refs.


No correlation was found between indicator bacteria and the presence of viruses in groundwater. Suggests that the expected movement of viruses vs. bacteria in groundwater should be different. 5 figs., 33 refs.


Comparative survival of various bacteria in flowing well water was as follows: Aeromonas sp. > the shigellae > fecal streptococci > coliforms = some salmonellae > Streptococcus equinus > Vibrio cholerae > Salmonella typhi > Streptococcus bovis > Salmonella enteritidis. 6 figs., 21 refs.


Extensive literature review. Topics include occurrence of enteroviruses in surface, marine, and groundwaters, mechanisms of viral transport, and viral survival in natural waters. 11 figs., 146 refs.

Moore, B. E., B. P. Sagik, and C. A. Sorber. 1981. Viral transport to ground water at a wastewater land application site. JWPCF 53:1492-1502

Sewage effluent was applied to calcereous well-drained soils with moderate permeability (1.5-5.1 cm/h), soil pH of 7.7-9.0, and CEC of 25-50 meq/100 g. Fecal coliform and fecal streptococci were reduced by 90% with 0.46 m. infiltration depth. Enteric viruses were found to travel to a depth of at least 1.37 m. 9 figs., 13 refs.


Saturated flow conditions in sandy soil resulted in movement of fecal coliforms to shallow (3 meter) water table. 2 figs., 14 refs.

A strong negative correlation was found between poliovirus adsorption and both the content of organic matter and the available negative surface charge on the substrates. The effects of surface area and pH were not strongly correlated with viral adsorption. 11 figs., 44 refs.


Found coliform multiplication in wells. High coliform counts found in the repumped water were the result of bacterial multiplication (growth) on the accumulated organic matter (consisting mostly of algal cells) which serves as a nutrient. 12 figs., 7 refs.


Coastal plains soils considered "marginally conducive" for sanitary disposal, due to seasonally fluctuating water tables and/or restricting layers, were investigated. Lateral movement of fecal coliform to at least 13.5 meters was observed, but fecal coliform did not penetrate confining layers to reach groundwater. 4 figs., 18 refs.


Wastewater applied to plots of unconsolidated silty sand and gravel. Indigenous enteroviruses and coliphage f2 tracer were sporadically detected in groundwater to horizontal distances of 600 ft from the application zone. Fecal strep which penetrated the surface layer also travelled this distance. Enteric indicator bacteria were concentrated on soil surface by filtration on soil surface mat. 12 figs., 15 refs.

Encephalomyocarditis viruses adsorb to introduced organic and inorganic material over a wide range of pH and with various concentrations of metal cations. Clay-adsorbed viruses maintained their infectivity. 9 figs., 41 refs.


Wetland organic soils (cypress domes) appear not to be suitable for application of wastewater for treatment. The presence of humic substances originating from these black organic sediments was shown to interfere with the sorptive capacity of soils and sediments toward viruses. 10 figs., 14 refs.


Fecal coliform were shown to travel 9 m from a 5.5 m deep soakage pit in an unconfined aquifer, and 42 m from an 18 m deep injection bore in a confined aquifer. Fecal coliform levels were reduced by a factor of 3 within the septic tank. 10 figs., 26 refs.


Clayey soils efficiently adsorbed poliovirus and reovirus from wastewater over a range of pH and total dissolved solids levels. Sands and organic materials were relatively poor adsorbents, though in some cases their ability to adsorb increased at low pH and with the addition of total dissolved solids or divalent cations; however, they did give > 95% virus removal from intermittently applied, unsaturated flow wastewater. Simulated rainfall through columns easily eluted viruses off sandy soils, but did not elute viruses from clayey soils. 10 figs., 24 refs.


E. coli was found to travel up to 65 feet after being added to
the saturated zone in fine sand (effective grain size of 0.13 mm)


The number of viable E. coli cells found in Pahokee Muck was approximately threefold greater than that found in Pompano fine sand after 8 days incubation. Greatest coliform survival was seen under anaerobic conditions. Coliform die-off appears to be controlled by biotic factors, including protozoa. Increased coliform survival in histosol compared to mineral soil was due to the higher organic content of the histosol. 6 figs., 15 refs.


Authors show persistence of fecal bacterial viability in feces to at least 8 weeks (10^6 reduced to 10^3 or 10^4) under field conditions during a snow free period.


A comprehensive review of the literature on the subject. Useful summary tables presented. 3 figs, 182 refs.


Tertiary-treated effluent was applied to recharge basins. High infiltration rates (75-100 cm/hr) resulted in movement of substantial numbers of poliovirus to groundwater. Infiltration rates of 6 cm/hr. significantly improved virus removal; highest viral removal efficiency was seen at very low infiltration rates of 0.5-1.0 cm/hr. 9 figs., 23 refs.

Authors document travel of human enteroviruses from a subsurface wastewater disposal system in an area of sandy unconsolidated soil with a shallow aquifer. Enteroviruses were detected at a lateral distance of 67.05 m and at aquifer depths of 18 m. Virus occurrence was not correlated with total or fecal coliform numbers. 5 figs., 25 refs.


Secondary- and tertiary-treated effluent was applied to recharge basins in sandy unconsolidated soil. Viruses were detected in groundwater where the recharge basins were located less than 35 feet (10.6 m) above the aquifer. Lateral entrainment of viruses to 45.7 m was noted at one site. 9 figs., 22 refs.


Secondarily treated wastewater was applied to 100 cm soil columns. Viral removal was primarily determined by flow rate. At 33 cm/day sandy loam removed 99% seeded poliovirus in first 7 cm. At 300 cm/day rubicon sand removed less than 90% in 100 cm. This study suggests that the rate of water flow thru the soil may be the most important factor in predicting viral movement into the groundwater. 9 figs., 23 refs.


Virus was shown to survive in groundwater for at least 28 days. 3 figs., 11 refs.


Secondary effluent was discharged to a cypress dome; underlying soil strata was organic matter, sand and relatively impermeable sand/clay layers. Study found viral percolation to 3.05 m depth, and 7 m subsurface lateral movement of virus. Virus survived at least 28 days in groundwater. 4 figs., 20 refs.

Temperature was found to be the single best predictor of virus persistence in groundwater. At lower temperatures (approx. 4°C) both poliovirus 1 and echovirus 1 persisted for up to 28.8 days before a 1 LTR (log titre reduction) took place. At 26°C, poliovirus survived 3-5 days before a 1 LTR took place. 3 figs., 19 refs.
EFFECT OF STORMWATER ON BACTERIOLOGICAL QUALITY OF COASTAL WATERS


For agricultural land use, frozen ground decreases infiltration and increases stormwater loading. Good summary of total coliform, fecal coliform, fecal strep, and total enterococci concentrations in a variety of animal manures. Even if best management practices are followed, $10^3 - 10^5$ organisms/100 ml should be expected as background. 4 figs., 82 refs.


Peaks of fecal coliform abundance are correlated with periods of heavy rainfall. 3 figs., 13 refs.


E. coli and Streptococcus faecalis survived in groundwater to 32 days. Neither bacteria was detected in wells 30 m distance on day 32, but sufficient time may not have elapsed for travel in groundwater to this distance. Rainfall caused a peak in the bacterial numbers in wells. 5 figs., 8 refs.


Discusses use of STORM, a U.S. Army Corp. of Engineers computer model, to predict pollutant loadings to surface and subsurface waters from a proposed large-scale residential development. 14 figs., 17 refs.

More than 50% of stormwater bacteria studied do not settle or become associated with settling sediments. However, an average of 16-47% do get into the sediments and can accumulate, and should be considered when assessing health risk. 7 figs., 28 refs.


Extensive summary of conclusions from NURP program. Discusses characteristics of urban runoff, effects of runoff on quality of receiving waters, and stormwater management and runoff controls.


Proceedings of a national conference. 133 papers on topics including: monitoring and assessment techniques; legal aspects of nonpoint source pollution; institutional/financial aspects of nonpoint source control; groundwater quality; lake quality; estuarine quality; streams and rivers; economics of nonpoint source pollution; agricultural issues; urban runoff; urban hydrologic modification and septic tanks; land use management and assessment; case studies; data availability and needs; and water quality criteria and standards.


Study on survival of E. coli and Streptococcus faecalis in outdoor soil plots. During summer, fecal coliform survived slightly longer than fecal strep; in autumn, survival was the same; and in spring and winter fecal strep survived much longer than fecal coliform. In summer and autumn both organisms at a protected hillside site survived about twice as long as at an exposed lawn site. Some aftergrowth of fecal and non-fecal organisms was observed as a result of temperature and rainfall variations; this may contribute to variations in bacterial counts in storm-water which have no relation to sanitary history of drainage area. 4 figs., 27 refs.

Chapter titles include: Introduction; Governmental Aspects of Stormwater Management; Storm Hydrology and Changing Land Use; Runoff Pollution; Stormwater Models; Erosion and Stormwater; Detention and Flow Retardation Devices; Floodplain and Channel Management; and General Planning and Management Aspects.


Report produced as part of NURP program. Volume 1 compares commercial, industrial, agricultural, high and medium density residential areas, and highways as sources of toxic metals, suspended solids, and phosphorus in stormwater. Concludes that pollution control program must be tailored to specific land uses. Volume 2 discusses applicability and economic considerations in use of streetsweeping, stormwater storage basins, and catch basin cleaning as methods for abatement of nonpoint stormwater pollution.
EFFECT OF WATERFOWL ON BACTERIOLOGICAL QUALITY OF COASTAL WATERS

Brierley, J. A., D. K. Brandvold and C. J. Popp. 1975. Waterfowl refuge effect on water quality: 1. Bacterial and high sediment concentration water typical of the southwestern U.S. An increased number of coliforms correlated with increased nutrients in flowing water was also found. 8 figs., 9 refs.

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No Campylobacter were isolated from water, sediment, or bird cecal samples gathered in migratory waterfowl roosting pools. High fecal coliform counts in water followed moderately heavy rainfalls on two occasions, and was attributed to a sudden influx of waterfowl on another occasion. 2 figs., 32 refs.

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Authors estimate that in a 24 h period a single swan will eliminate up to $10^9$ fecal coliform and a goose will eliminate up to $10^7$. Wild birds, as opposed to captive birds, found to harbor significantly more fecal coliforms than fecal streptococci. Neither Salmonella or Shigella were isolated from migratory waterfowl. 3 figs., 24 refs.
EFFECT OF MARINE CRAFT ON BACTERIOLOGICAL QUALITY OF COASTAL WATERS

Faust, M. A. 1978. Contribution of pleasure boats to fecal bacteria concentrations in the Rhode River estuary. unpubl. ms., Chesapeake Bay Center for Environmental Studies, Edgewater, MD.

In an estuarine area, bacterial concentrations rose from 3 to 28 fecal coliforms per 100 ml, and from 7 to 68 fecal streptococci per 100 ml after the arrival of pleasure boats for the weekend. Author calculates that $10^{-20} \times 10^4$ m$^3$ of water is required per boat to keep fecal coliform levels below the shellfish limit of 100 FC/100 ml. 4 figs., 20 refs.


Water taken from each of 6 marinas tested was found to have significantly higher total and fecal coliform than surrounding waters. Three marinas catering primarily to pleasure craft had higher levels of fecal coliform in marina waters on days following a weekend or holiday than on weekdays. No water from any of the marinas sampled met required standards for shellfish growing waters (14 FC MPN/100 ml). 15 figs., 9 refs.